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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Braking system	Mobility
*Fuel system (automotive)	Side-slope mobility
Gradeability	Vehicle, tracked
Hill-climbing ability	Vehicle, wheeled

*New

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Describes procedures for evaluating vehicle gradeability and side-slope performance. Discusses payload, inspection, vehicle performance, safety, and instrumentation. Includes procedures for calculating the critical grade angle prior to testing and for evaluating brakes, engine, transmission, fuel system, and steering performance during testing. Applies to wheeled and tracked vehicles.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-101
*Test Operations Procedure 2-2-610 — 18 July 1980
AD No.

GRADEABILITY AND SIDE-SLOPE PERFORMANCE

1. SCOPE. This TOP describes the procedure for evaluating wheeled and tracked vehicle performance on various longitudinal grades and side slopes to assure conformance with the applicable Required Operational Capability (ROC), Development Plan (DP), or other guidance document. Included are procedures for evaluating engine, transmission, brakes, fuel system, safety, and vehicle control during grade and slope testing.

The gradeability of a vehicle is a measure of its capabilities for operating on slopes. This characteristic is of particular importance in military vehicles, which must be capable of operating in any tactical situation without relying on established roadways. The evaluation of the gradeability and side-slope performance of a vehicle on calibrated grades provides a means for determining the adequacy of the mobility of the equipment, and provides for an assessment of the tractive ability of the item.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENTS
Longitudinal grades and side slopes	As described in TOP 1-1-011 under gradeability slopes (5, 10, 15, 20, 30, 50, and 60 percent and side slopes (20 to 40 percent)

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*This TOP supersedes TOP 2-2-610, 21 October 1976.

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ITEM (CONT)	REQUIREMENTS (CONT)
Safety vehicle (wrecker) with safety cable	Vehicle with cable of sufficient size and strength to safely restrain the test vehicle in the event of tipping or mechanical failure.

2.2 Instrumentation.

ITEM	MAXIMUM ERROR OF MEASUREMENT*
Engine tachometer	±0.5% of full-scale range
Vehicle speed-measuring device (calibrated fifth wheel with speed indicator)	±0.2 km/hr (±0.2 mph)
Pressure-measuring equipment	±1% of full-scale range

*Values may be assumed to represent 2 standard deviations; thus the stated tolerances should not be exceeded in more than 1 measurement out of 20.

3. PREPARATION FOR TEST.

3.1 Test Vehicles. All vehicles to be tested on slopes are first loaded with their cross-country payload or combat weight unless otherwise specified. Payloads are blocked, as appropriate, and securely fastened to prevent shifting during the test, except when the test requires loose sand, gravel, crushed stone, or specially prepared palletized payloads with interlocking capabilities to form a single unit. When the vehicle is towing a rated load, the tests are conducted both with and without the load. Maintenance and service operations are performed to insure that the test vehicle is in condition for optimum performance, with particular attention being given to the engine, transmission, brakes, and running gear. Vehicle characteristics data are collected in accordance with TOP/MTP 2-2-500.

3.2 Instrumentation. The vehicle is instrumented to determine the engine speed and road speed of the vehicle and to monitor the fuel and oil pressures. The instrumentation commonly used consists of a calibrated fifth wheel with a speed indicator, an engine tachometer, and the appropriate pressure gages. When torque and steering evaluations are conducted as part of this test, additional instrumentation is required, as described in TOP/MTP 2-2-806 and TOP 2-2-609, respectively. Appropriate instrumentation is also installed to monitor any other parameter required for safe vehicle operation.

3.3 Determination of Critical Angle.

3.3.1 Basic Information. When approaching and ascending slopes of critical grades, vehicles tend to tip over backward about some rear pivot point. In theory, the critical point is reached when the center of gravity (CG) of the vehicle is located vertically above the center of rotation (Figure 1). In practice, the critical angle is always less than the theoretical value in both static and dynamic tests. In static testing, the sagging of the rear suspension members, resulting from the change in the direction of forces, causes the CG to shift rearward. In dynamic or operating tests, this condition is augmented by the torque in the driving members, especially if any acceleration is attempted. Irregularities in the road surface can add tendencies to overturn.

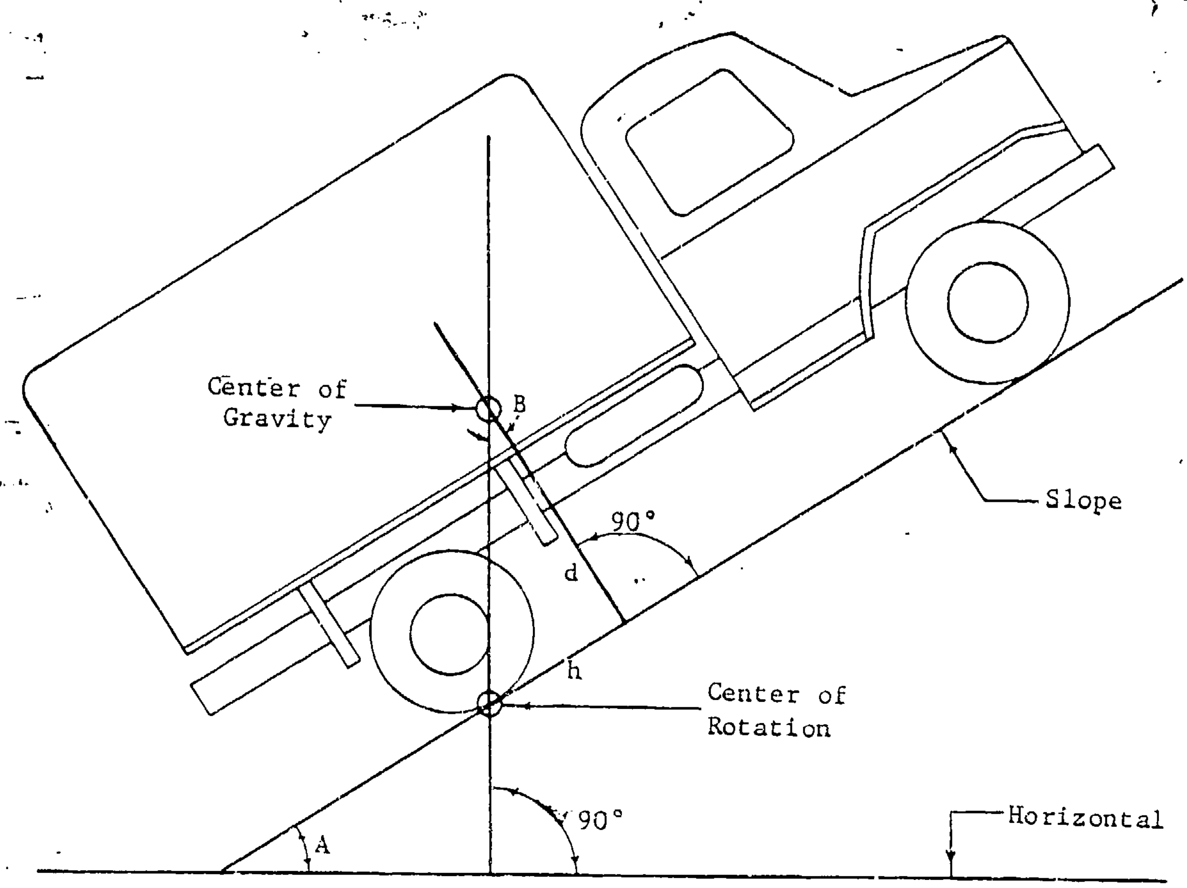

Figure 1. Critical Angle for Vehicle on a Slope.

3.3.2 Calculation. The theoretical tipping angles (critical angles) are calculated for both ends and both sides of the test vehicle before testing to establish a rough approximation of the maximum slopes on

which the vehicle can safely operate. For these calculations the vehicle is assumed to be loaded with its rated load, and the combined CG location is determined in accordance with TOP 2-2-800. With the vehicle on level ground, the height (d) of the CG location above ground and horizontal distance (h) between the CG location and the center of rotation (in this case, the rear wheels) are measured. These measurements are used in the following equations to find the theoretical values for the critical angle and the critical grade (slope) in terms of percentage:

$$\text{Critical Angle B} = \tan^{-1}\frac{h}{d}$$

$$\text{Critical Grade (\%)} = 100\,\frac{h}{d}$$

The relationship between angle and grade is shown in Figure 2. At the critical angle, the CG is directly above the center of rotation. Under these conditions Angle A equals Angle B.

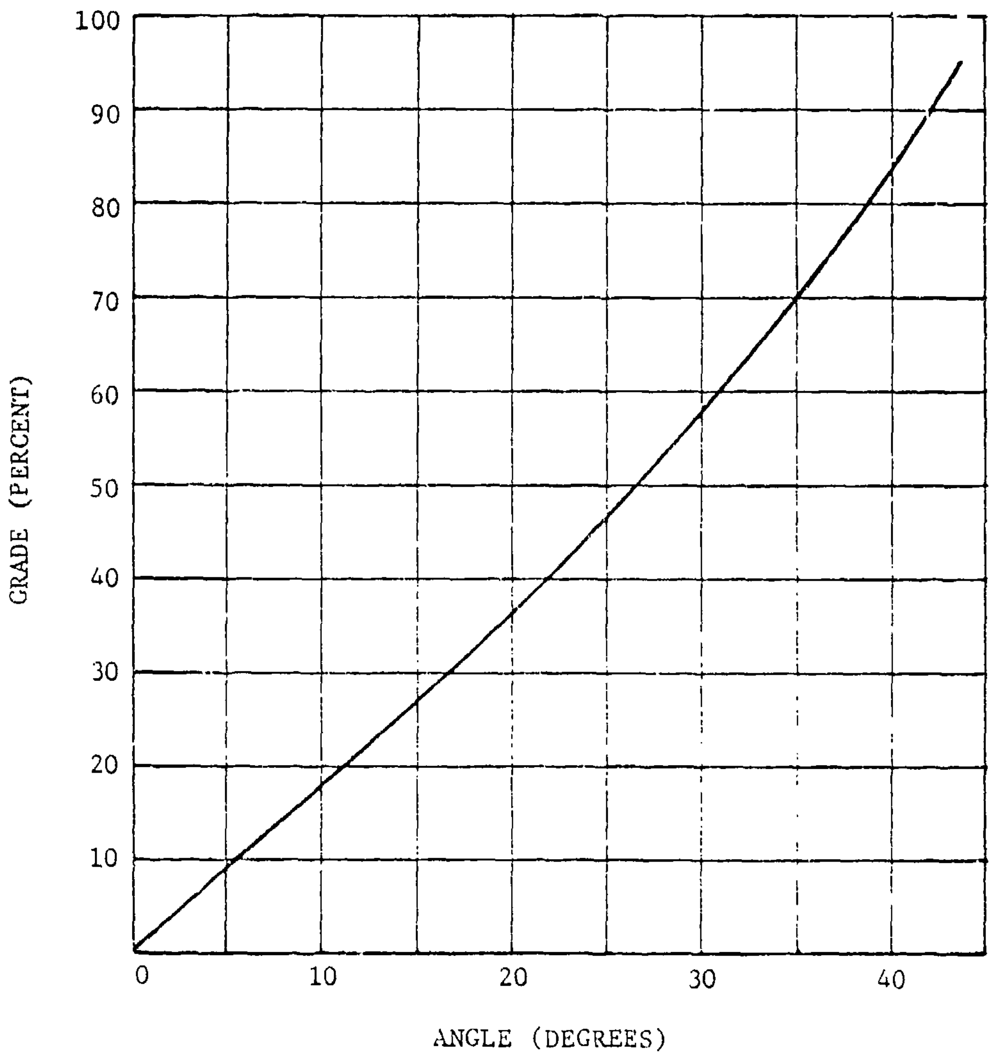

Figure 2. Conversion between Grade and Angle

The prior procedure presumes that the CG lies more toward the rear of the vehicle; therefore, the rear wheels were used as the center of rotation and the critical angle obtained for ascending a slope. Should the CG be more toward the front of the vehicle, the front wheels would be used as the center of rotation and the critical angle thus determined would apply to descending a slope.

Critical angles for side-slope operation are obtained in a similar manner.

4. TEST CONTROLS.

a. All safety procedures are observed throughout test operations. In particular, safety cables are attached to all test vehicles when negotiating longitudinal slopes exceeding 40 percent in grade and all side slopes. Operation without safety cables may be permitted only after it has been proven by previous tests, using a safety cable, that the vehicle can safely negotiate the specified slope.

b. Correct levels of lubricant, hydraulic fluid, coolant, etc., are maintained throughout the tests.

c. Vehicles are operated until their normal operating temperatures are reached before initiating each test.

5. PERFORMANCE TESTS.

5.1 Longitudinal-Grade Performance. Army specifications require that military tactical vehicles be able to negotiate a 60-percent grade in both forward and reverse gears and be able to brake adequately on this grade. In addition, the vehicle is required to demonstrate gradeability on more realistic grades at speeds specified without stalling, upsetting, slipping (losing traction), or overheating the engine. The prepared slopes used in testing vehicles include 5-, 10-, 15-, and 20-percent grades with blacktop paving and 30-, 40, 50-, and 60-percent concrete grades.

In some vehicles, fuel and oil pressures are adversely affected by slope operation. These pressures are observed during slope operations and compared with pressures obtained during level-road operations.

5.1.1 Holding Ability of Brake. The braking system shall be capable of stopping and holding the vehicle in both forward and reverse directions on the maximum slope the vehicle was designed to ascend.

5.1.1.1 Method. Drive the vehicle fully onto the 60-percent slope (or other slopes as specified). Near the bottom of the slope, the vehicle is brought to a full stop, the brakes applied, the transmission placed in neutral, and the holding ability of the brakes is checked. Holding ability of the vehicle parking brake is also assessed with the engine shut off.

When a towed load is prescribed, brake tests are performed both with and without the load. The maximum slope that can be attempted with a towed load may be limited, however, by design factors which restrict the angle of approach and/or departure.

5.1.1.2 Data Required.

a. Observations on each slope attempted.

b. Towed load, where applicable.

c. Load carried.

5.1.2 Engine and Transmission.

5.1.2.1 Method. While holding the vehicle on the maximum grade, idle the engine for two minutes; shut it down for two minutes, and then restart it. The transmission is then engaged and the throttle increased as the brakes are released, to determine the ability of the vehicle to continue up the slope. When applicable, the auxiliary engine is also checked for idling and restart capability.

The procedure described above is repeated with the vehicle headed both upgrade and downgrade.

For vehicles with torque-converter transmissions, the engine speed at vehicle stall is observed, usually on both 50- and 60-percent slopes. This observation is made with the vehicle in both ascending and descending attitudes; in the latter case, the check is made with the transmission in reverse. This will indicate whether the engine is delivering suitable torque and horsepower.

5.1.2.2 Data Required.

a. Fuel and oil pressures.

b. Engine speed.

c. Observations of idle, restart ability, and ability to continue up the slope.

d. Load carried.

5.1.3 Grade Speed Test.

5.1.3.1 Method. Determine the sustained speed of the test vehicle on the steeper grades by bringing the vehicle to a maximum slope speed from a standing start on the grade. The necessary trials are made to

insure the use of the optimum gear or range for maximum performance on a given grade. The maximum reverse speeds are measured on the grades, when appropriate; in any case, the maximum gradeability (up to 60 percent) in reverse is determined.

On slopes of lesser gradient, the maximum sustained speeds are obtained by running repeatedly on the slope, moving from a standing start. Subsequent runs are approached at a speed just below the previous maximum. This process is continued until the terminal speed is reached.

5.1.3.2 Data Required.

a. Road and engine speeds, and gear ranges of each run.

b. Oil and fuel pressures.

c. Load carried.

NOTE: When no facilities are available for determining slope performance at a desired gradient, the slope performance of the vehicle can be calculated from drawbar-pull performance on level roads (TOP 2-2-604). By referring to drawbar-pull curves, the gradeability of a vehicle at a given speed may be secured, or the maximum speed at a given gradient may be determined. The formulas for making these determinations are:

$$\sin \theta = \frac{P}{W}$$

$$\text{Percent gradient} = (\tan \theta)\ (100)$$

where

θ = Angle of the gradient.
P = Drawbar pull, pounds.
W = Vehicle weight, pounds.

5.2 Side-Slope Performance. Military vehicles are tested to determine their operating ability on side slopes ranging from 20- to 40-percent grades, as indicated in the applicable specifications.

5.2.1 Method. Run the vehicle the horizontal length of the specified side slope in both directions with a check of steering control being made by running a sine-wave pattern. The steering of vehicles on slopes is covered in TOP 2-2-609. With the vehicle headed first in one direction and then the other, an idle run of the engine is conducted for not less than 2 minutes, after which the engine is stopped and then restarted. When applicable, the same procedure is followed for the auxiliary engine.

During slope operation, overflows of liquid containers and reservoirs are checked, as well as the possibility of fuel flowing from the high to the low tank. Vehicles having a high CG will have their maximum side-slope ability checked with the aid of special safety precautions.

5.2.2 Data Required.

a. Engine speed.

b. Fuel and oil pressure.

c. Steering observations.

d. Engine starting ability.

e. Vehicle stability.

f. Load carried and distribution, and location of CG.

5.3 Other Performance Factors. Throughout all longitudinal-grade and side-slope performance tests, additional observations are made and data collected as appropriate to determine the effect of grades and slopes on other performance factors. Specific observations are made of:

a. The ability of the driver to remain in position to control the vehicle (i.e., steer, apply brakes, visibility).

b. The security of payloads (TOP/MTP 2-2-537).

c. The security of tools and other on-equipment materiel (OEM) (TOP 2-2-802).

d. Adequacy of vehicle design to accommodate the angles of approach, departure, and breakover (TOP 2-2-611).

6. DATA REDUCTION AND PRESENTATION. The data obtained for each subtest are presented in tabular form and compared with established criteria.

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